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Putting enzymes to work™

LOW ENERGY CO_2 CAPTURE ENABLED BY BIOCATALYST DELIVERY SYSTEM

2015 NETL CO2 Capture Technology Meeting
Pittsburgh, PA.

Project: DE-FE0012862

June 24, 2014

PROJECT OVERVIEW

Participants, Duration, Funding

- **Project awardee and subcontract for TEA:**

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WorleyParsons
resources & energy

- **Enzyme Supply:**

novozymes
Rethink Tomorrow

- **Duration: 36 months (Oct 2013 to Sept 2016)**

- **Funding:**

DOE Funding:	$ 4,053,160
Akermin Cost share:	$ 1,013,289 (20%)
Total Project:	$ 5,066,449

PROJECT OBJECTIVES

- Modify existing pilot unit
- Assess performance of a new non-volatile, environmentally benign solvent
- Demonstrate *on-stream* biocatalyst maintenance
- Complete six-month demonstration at the National Carbon Capture Center (NCCC)
- Meet Techno-Economic Analysis Estimates
  - parasitic power: <220 kWh/t CO_2
  - capital costs reduced by >20%
  - cost of capture reduced by >30%

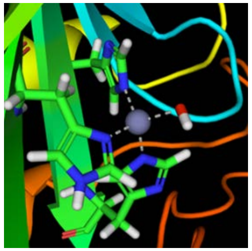
90% CO2 capture is assumed for all DOE goals

TECHNOLOGY BACKGROUND

- Chemical absorption of CO_2 in a novel low-energy solvent accelerated by a catalysts, carbonic anhydrase (CA)

$$CO_2 + H_2O \underset{}{\overset{\text{enzyme}}{\rightleftharpoons}} H^+ + HCO_3^-$$

$$B^- + H^+ \rightleftharpoons BH$$



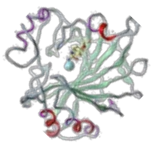
$$k_{cat}/K_M = 10^8\ M^{-1}s^{-1}$$
$$k_{cat} = 10^6\ s^{-1}$$

Challenge: how to make an enzyme evolved in nature work in harsh industrial environments?

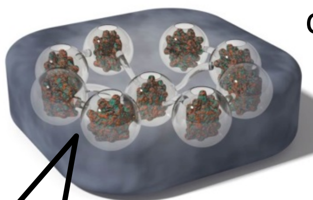
- Temperature (40- 105 °C)
- Extreme pH
- Impurities (SOx, NOx, etc.)
- Shear Forces
- Multiphasic systems

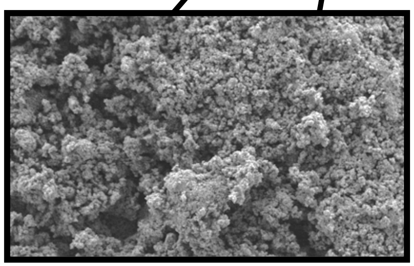
Enzyme engineering and advanced enzyme delivery systems are critical for solving the problem

AKERMIN'S BIOCATALYST DELIVERY SYSTEM



Enzyme

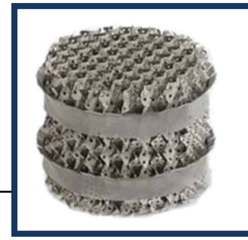


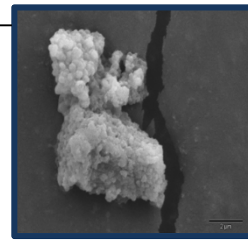


High surface area polymers enable higher mass transfer rate

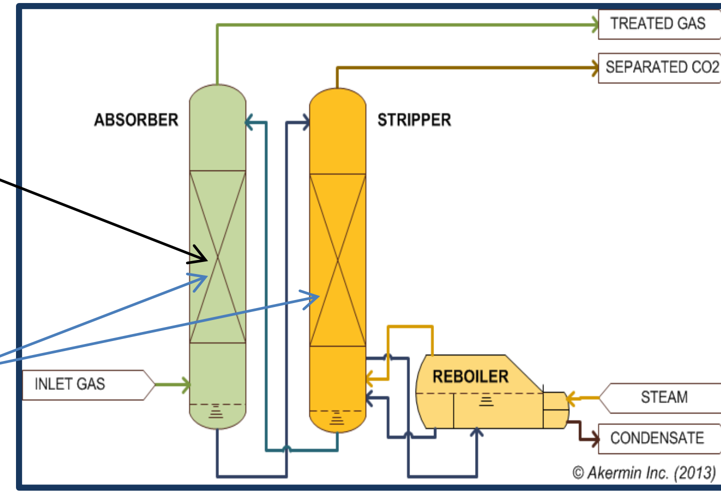
options for biocatalyst delivery

1st generation Coated packing





2nd generation Micro-particles



Successful biocatalyst approach enables:

- Non-toxic, non-volatile solvent(s)
- Novel process schemes

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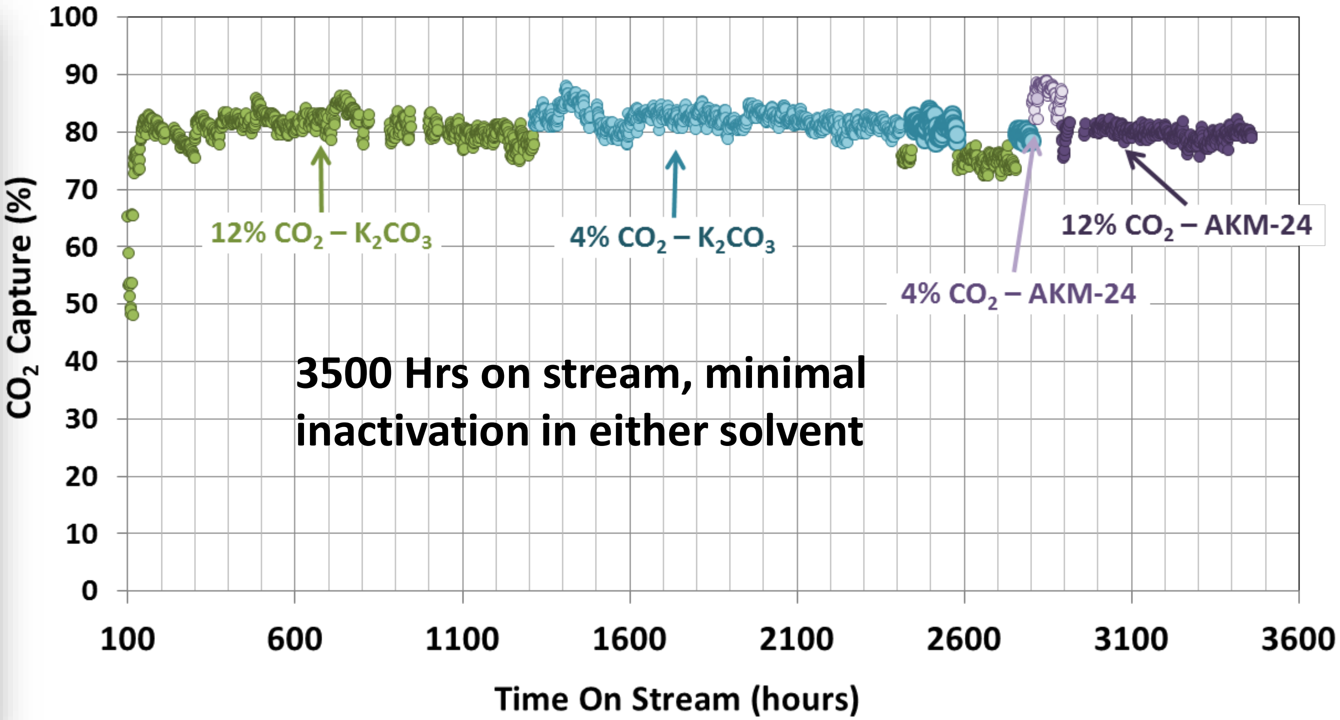
PROOF OF CONCEPT: CATALYST ON PACKING

Two solvents tested: K2CO3 and AKM24 (May – Oct 2013)



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REMAINING CHALLENGES: FURTHER REDUCTION OF ENERGY AND *IN SITU* BIOCATALYST REPLACEMENT

- Introduce new solvent, AKM-24
  - High CO_2 loading
  - Low regeneration energy
  - Non-volatile
  - Thermally stable
  - Highly water-soluble
  - Manufacturing route established
  - Low EH&S risks

- Replace catalyst on packing with catalyst in suspension

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CATALYST RECIRCULATION OPTIONS

Within the absorber only	Within absorber and stripper
Efficient particle separation	No separation is needed
Moderately thermostable CA	Highly thermostable CA
Lower rate catalyst inactivation, less frequent catalyst replacement	Higher rate catalyst inactivation, more frequent catalyst replacement
Fewer performance issues expected	Likely issues with particles in the striper (inactivation, foaming)
Standard high temperature stripper	Lower temperature stripper with vacuum; extra stage of compression

- In addition, the economics of both options needs to be considered:
  - Equivalent work of CO_2 capture for either option
  - Overall cost of capture (including the enzyme)

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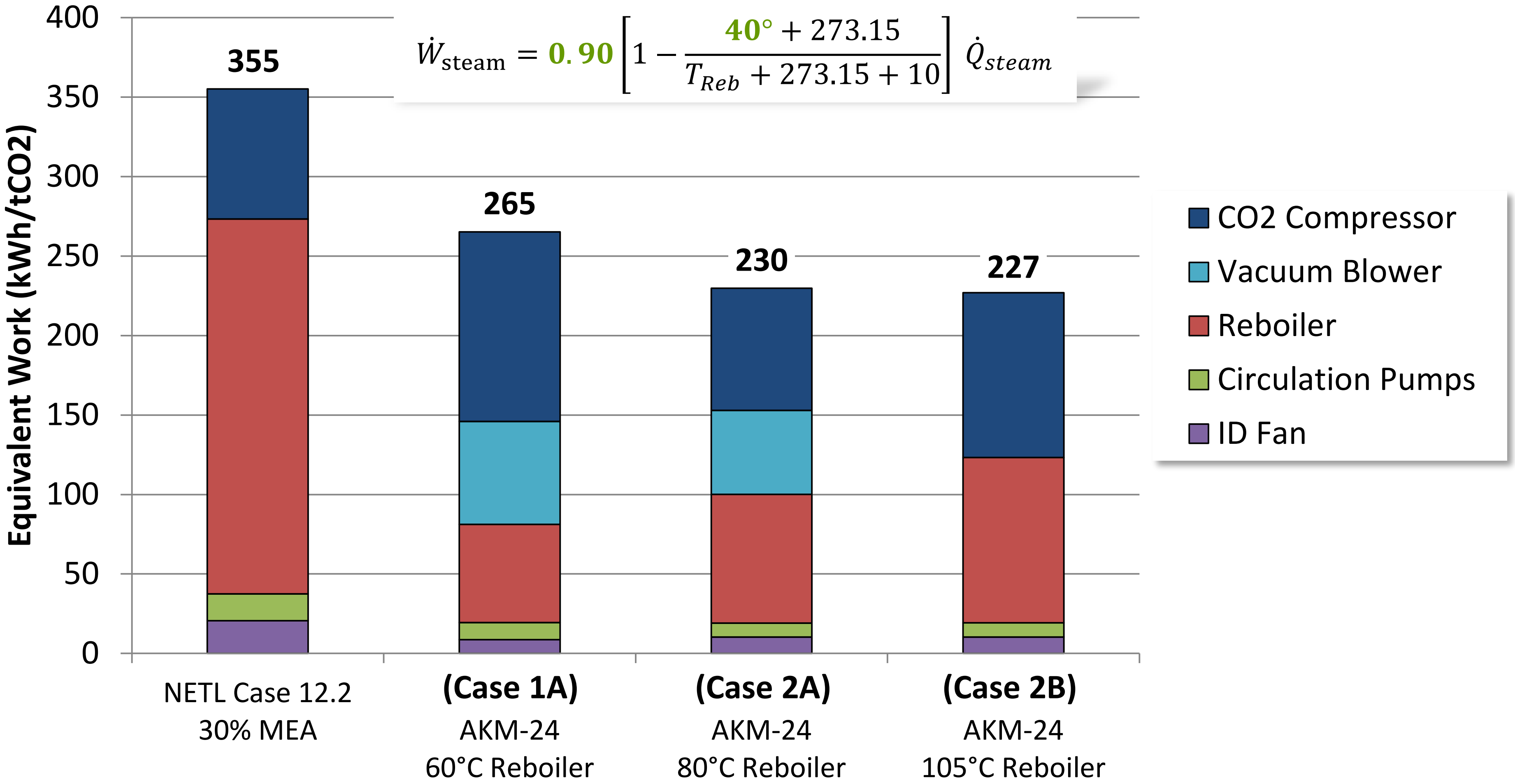
TOTAL EQUIVALENT WORK ESTIMATES

Milestone

Total equivalent work using Aspen after input of thermodynamic and kinetic data

$$\dot{W}_{\text{steam}} = \mathbf{0.90}\left[1 - \frac{\mathbf{40^\circ} + 273.15}{T_{Reb} + 273.15 + 10}\right]\dot{Q}_{steam}$$



>35% reduction relative to baseline (Case 12 , Rev. 2)

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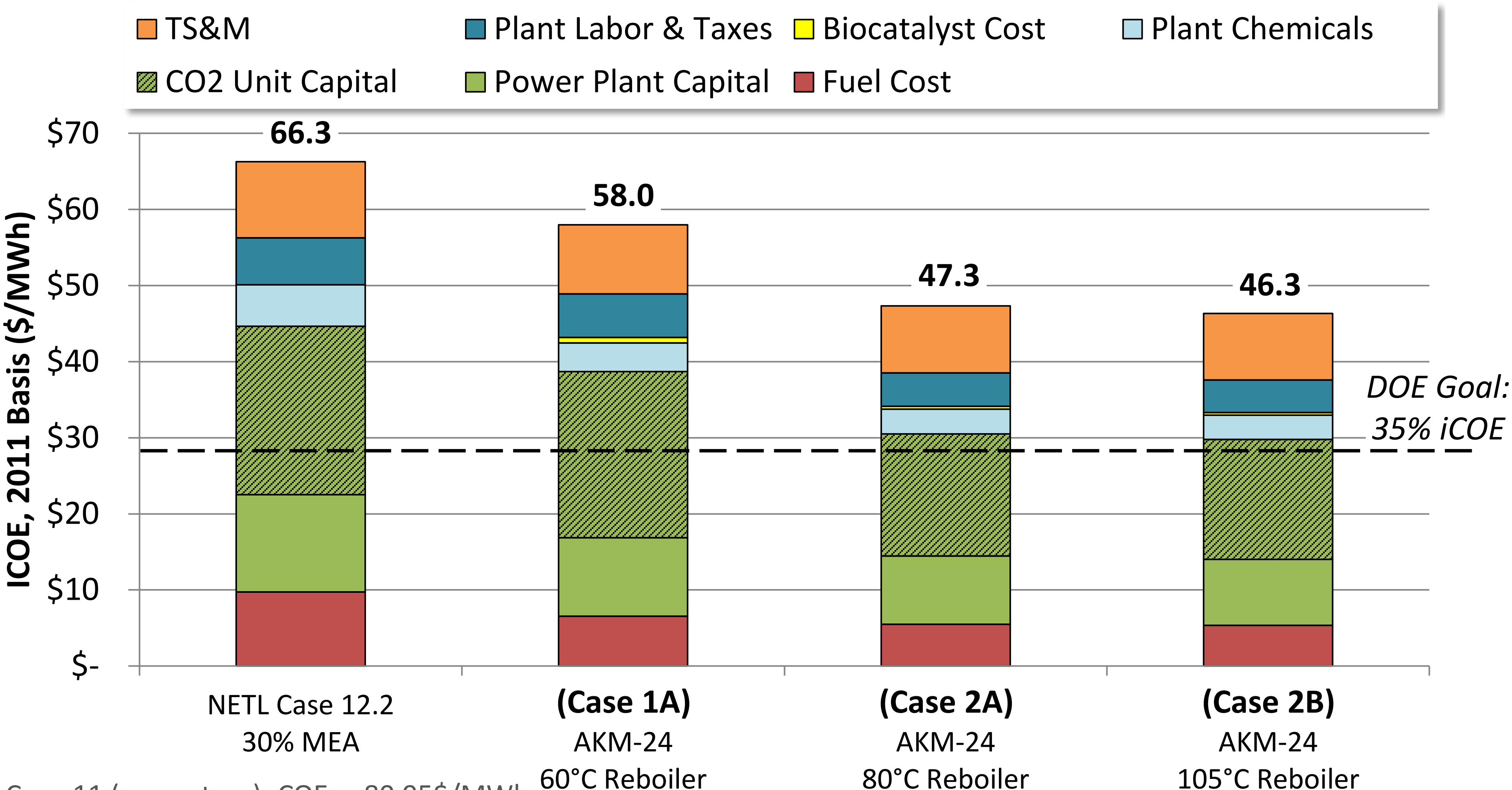
INCREASE IN COST OF ELECTRICITY OVER CASE 11 "NO CAPTURE"

Milestone



Case-11 (no capture): COE = 80.95$/MWh
assumes 1 year half-life and efficient BRS

~30% reduction in ICOE

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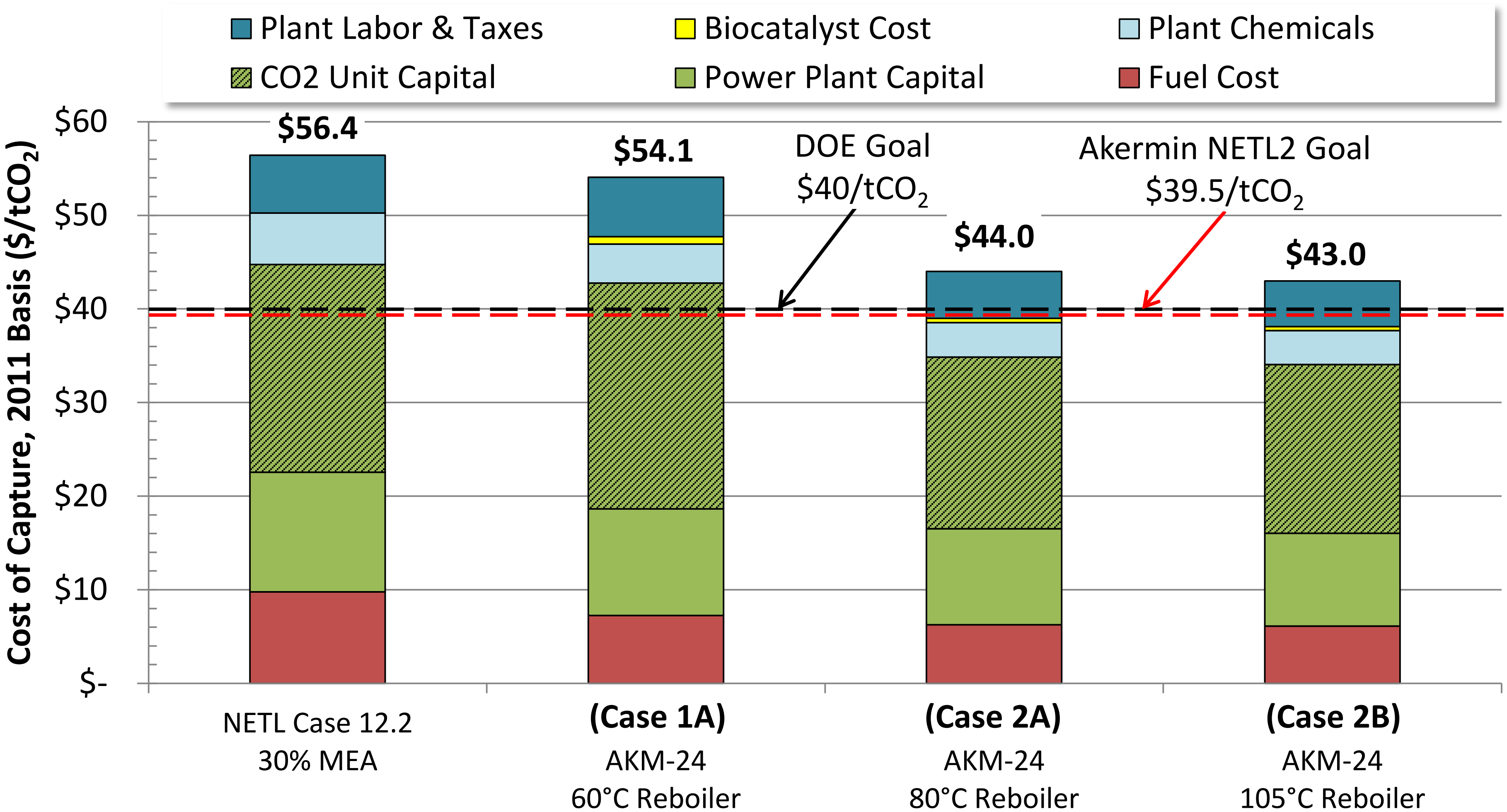
COST OF CAPTURE FOR VARIOUS CAPTURE SYSTEMS

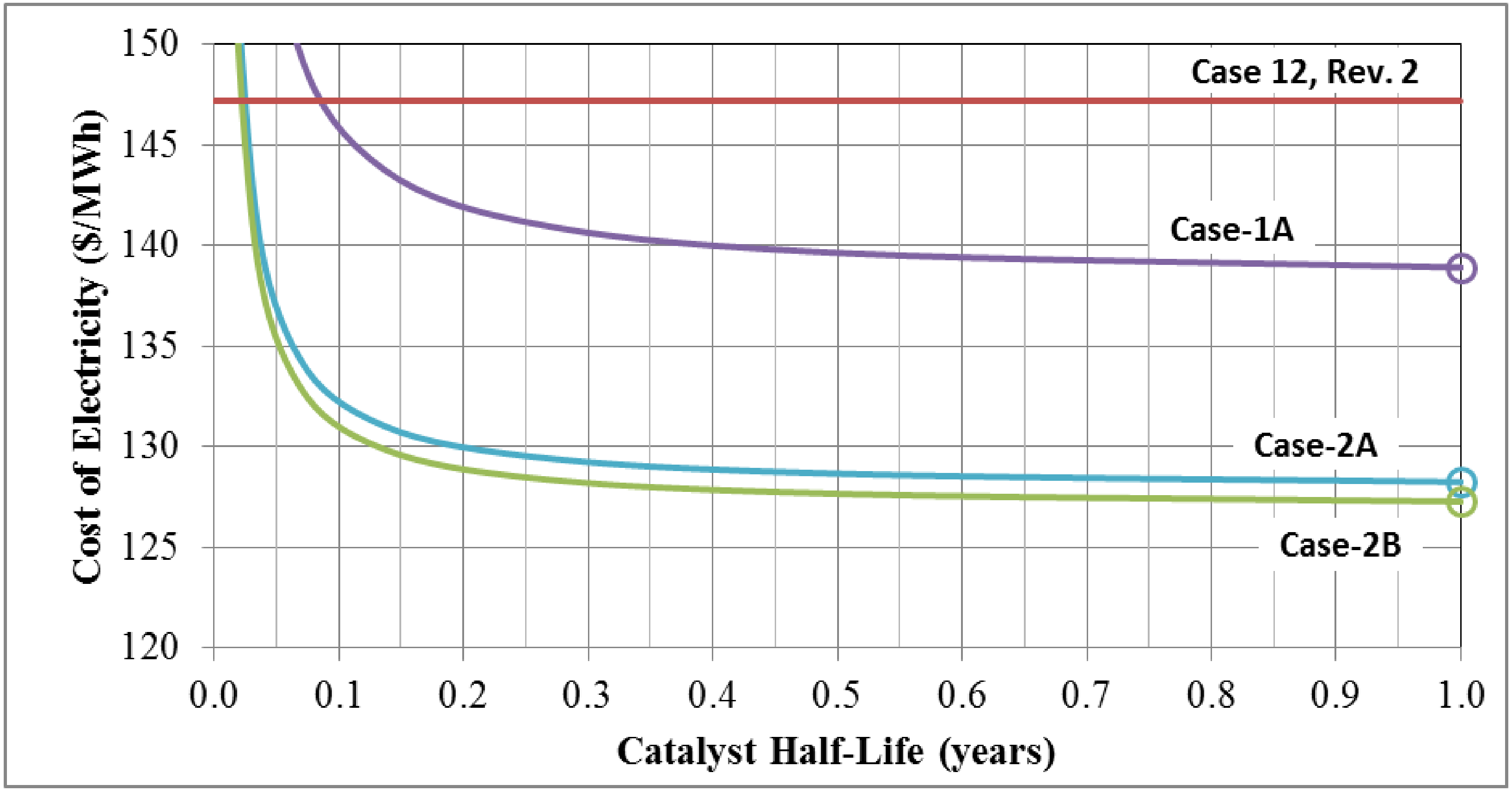
Milestone



~20% reduction in cost of capture appears achievable

Milestone

EFFECT OF BIOCATALYST HALF-LIFE ON COE



Minor effect with half-life exceeding 100 days

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FLOW DIAGRAM FOR PROCESS WITH CATALYST SEPARATION AND STRIPPING AT 105 °C

Absorber Lean Liquid:

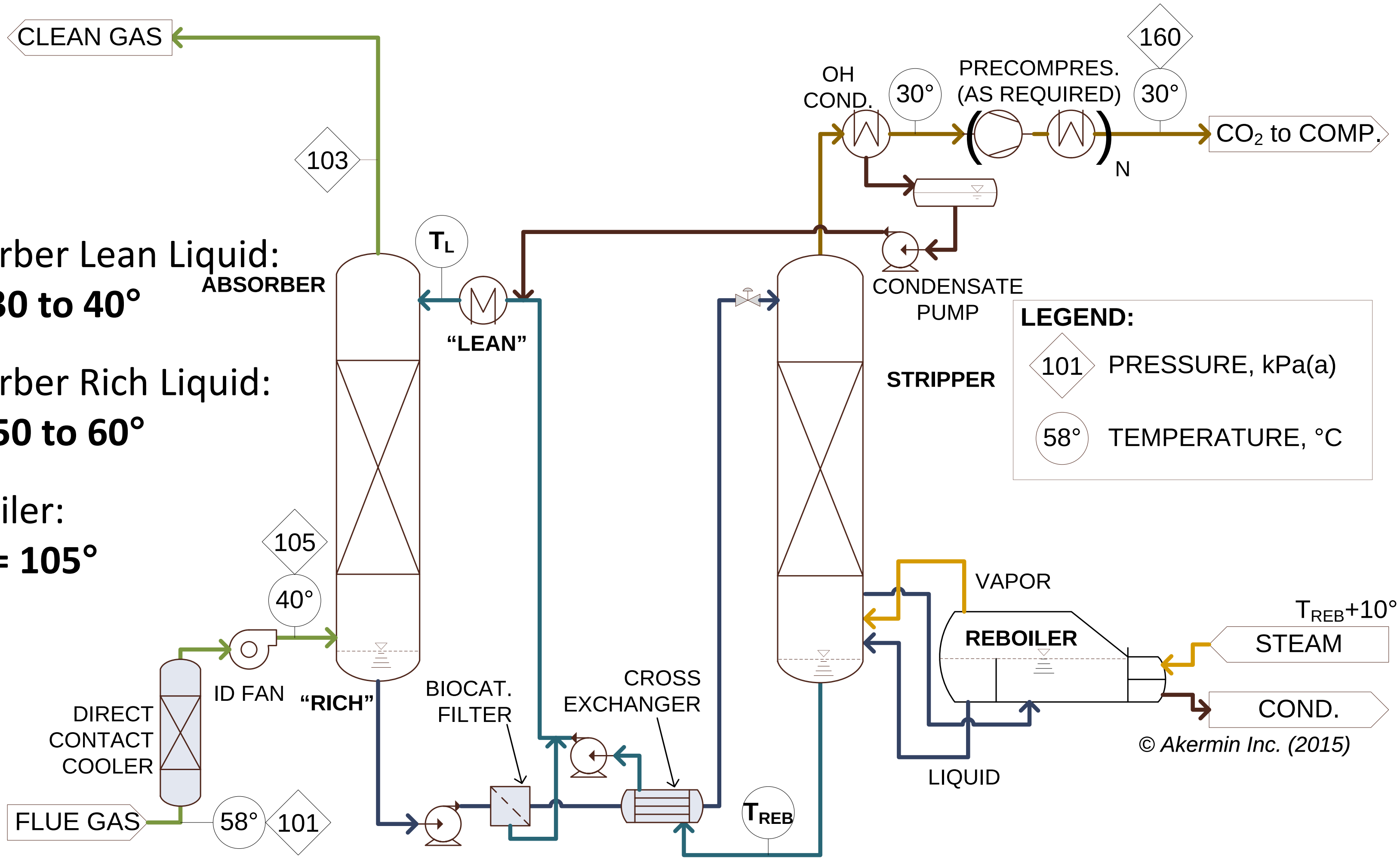
T_L = 30 to 40°

Absorber Rich Liquid:

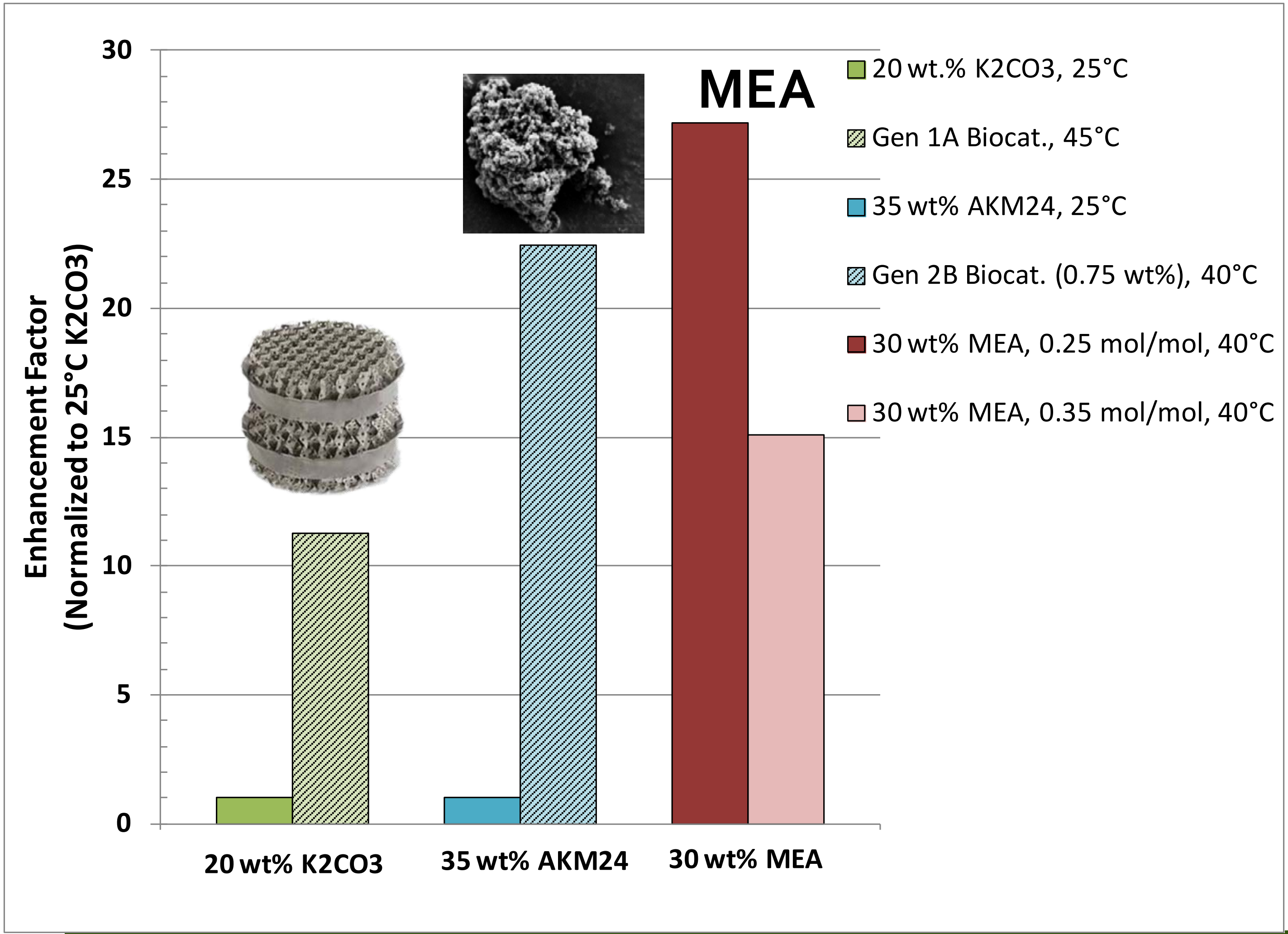
T_R = 50 to 60°

Reboiler:

T_{REB} = 105°



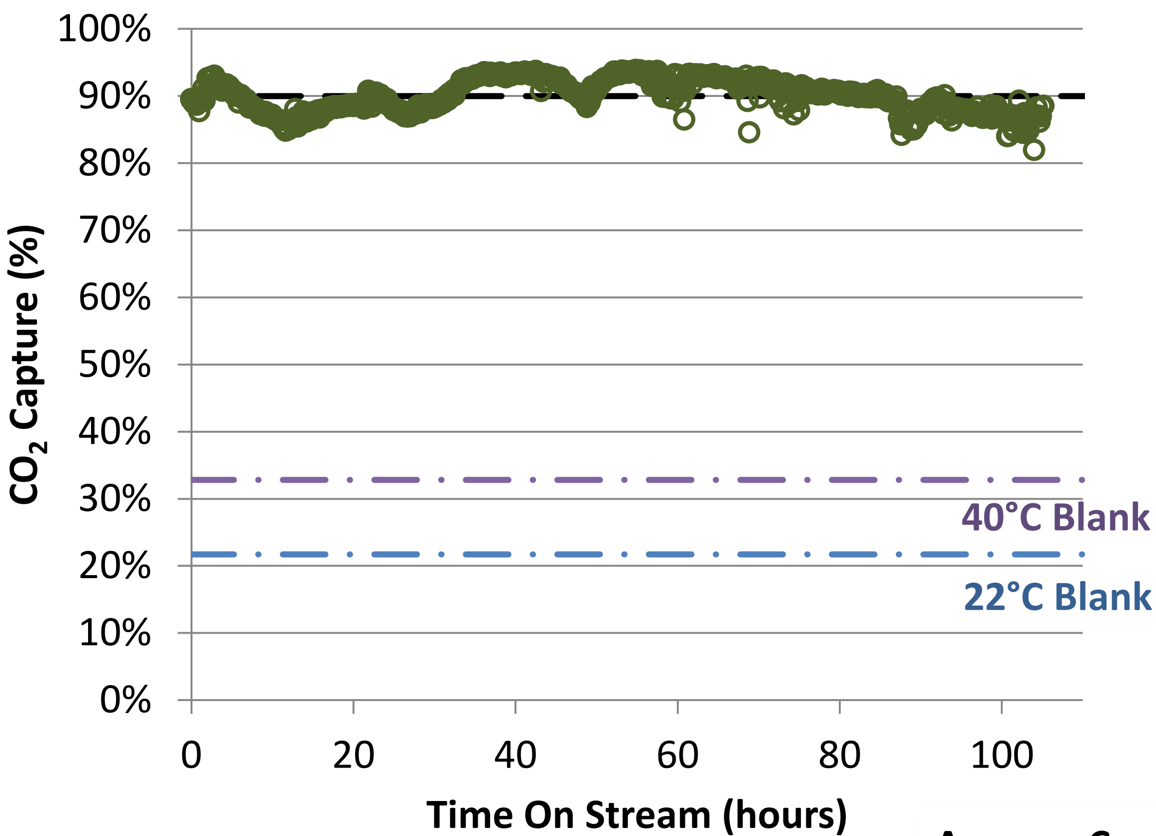
ENHANCEMENT FACTORS FOR ENZYME ON PACKING AND MICROPARTICLES VS. MEA



CO_2 CAPTURE OVER TIME: CLOSED LOOP REACTOR WITH BIOCATALYST SEPARATION

Milestone

2 LPM AKM24 @ 30 wt.%, 15 SLPM Gas Flow (13.3% Inlet CO_2), 35-40 ℃ Column @ 2 psig



Average Capture: 90%

SUMMARY OF PROGRESS TO DATE

- Produced and tested multiple biocatalyst batches on kg-scale
- Installed lab-scale closed loop reactor
- Demonstrated >20X biocatalyst enhancement
- Completed 100-hrs on-stream test, demonstrated avg. 90% capture
- Generated equilibrium and rate data for baseline AKM24 for a range of concentrations, temperatures, and CO_2 loadings
- Built enzyme kinetic model in Aspen and validated with data
- Identified cases with total equivalent work < 230 kWh/t CO_2
- Identified low cost biocatalyst separation option
- Completed Process Safety Analysis

FUTURE WORK AND NEXT SCALE ACTIVITIES

Commercial scale Biogas treating unit

- Size: 500 Nm³/hr. biogas
  - (50% of avg. commercial unit)
- $7 MM, three year project
- 50% funding through EUDP (Danish Energy Agency)
- Schedule:
  - Project Kickoff – Jan 2014
  - Commissioning – Nov 2015
  - Start Operations – Dec 2015
- 24 months operation and testing

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AMMONGAS

BIOFOS

DGC

EUDP Energiteknologisk udvikling og demonstration

Upgrading biogas to pipeline specification at industrial scale using biocatalyst

- **DOE/NETL:** *This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number DE-FE0004228.*